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Preface to special section on Arctic Ocean Model Intercomparison Project (AOMIP) Studies and Results

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1. Introduction

[1] More than 130 years ago, the Austrian Arctic explorer, Carl Weyprecht [*Weyprecht and Ihne*, 1913] (who discovered Franz Josef Land, an archipelago north of Russia, and who advanced a successful scheme for international cooperation in polar science—the International Polar Year concept) postulated that a number of fundamental problems of meteorology and geophysics could be solved near the Earth's poles. This hypothesis is still valid in the 21st century because the Arctic is recognized as a region where global climate change signals are amplified. The model-based conclusion of *Manabe and Stouffer* [1994] that the first signs of climate change could be detected in the Arctic has been corroborated by numerous other model results [e.g., *Holland and Bitz*, 2003; *Symon et al.*, 2005]. On the other hand, it has been demonstrated that model conclusions may be highly uncertain and that model estimates of future climate change differ significantly from model to model. In order to reduce these uncertainties, it is important to validate and to improve models. The latter is the first major goal of the Arctic Ocean Model Intercomparison Project (AOMIP). The second major AOMIP goal is to investigate variability of the Arctic Ocean and sea ice at seasonal to decadal timescales, and identify mechanisms responsible for the observed changes. Some of the latest AOMIP activities associated with these project goals are reflected in the papers of this special section.

[2] AOMIP was initiated in 2000. Briefly, this project has created a broad based "community" of directly involved arctic modelers from the United States, Canada, Germany, United Kingdom and Russia. The community-based modeling approach provides the unique opportunity to coordinate the investigation of different aspects of Arctic Ocean dynamics and thermodynamics because it allows the group to design a set of carefully-planned numerical experiments covering the most important processes and interactions. A clear advantage is that each AOMIP participant is able to work with his specific research theme using simulation results from all AOMIP models and to analyze differences among all model results, test different hypotheses employing both their own and other AOMIP models. This approach allows AOMIP collaborators to carry out comprehensive studies of different processes and interactions and to investigate the temporal and spatial variability of the Arctic's ocean and sea ice. It was expected that the main contribution from AOMIP would be: (1) identification of model errors and cause of those errors and model discrepancies; (2) recommendations for improving existing regional and global coupled ice-ocean models by implementing new physics and parameterizations for the Arctic processes; and (3) to assess the degree of uncertainty in the results and conclusions made by different modelers, scientific groups and institutions.

[3] At present, the AOMIP group consists of a core of nine principal investigators, and a large number of co-investigators from different countries. A web site for the AOMIP project has been created and can be accessed at http://fish.cims.nyu.edu/project_aomip/overview.html. This site serves as the focal point for electronic exchange of all modeling related intercomparison activities. A description of the various contributing models, the forcing data sets, the seasonal climatology, and the interannual variability runs are served and archived at the site. Additionally, reports on the various AOMIP workshops are provided. So far, two EOS publications [*Proshutinsky et al.*, 2001, 2005] have outlined the major AOMIP results for the broad community. More specific results can be obtained from project publications (peer-reviewed papers, book chapters, abstracts, posters and workshop reports) listed at the project web site.

2. Intercomparison Considerations and Paper Grouping

[4] There are several types of AOMIP papers in this section. Each paper (to some degree) contributes to both major AOMIP goals performing model intercomparison, validation and/or improvement (goal 1) and investigating variability and changes in the Arctic Ocean (goal 2).

[5] Separation of papers based on their primary relevance to the major AOMIP goals results in the following groupings.

[6] The first group of publications focuses on the analysis of differences among model results [e.g., *Holloway et al.*, 2007] and between model results and observations [e.g., *Johnson et al.*, 2007; *Martin and Gerdes*, 2007; *Gerdes and Köberle*, 2007]. This is important for determining model errors and model uncertainties, and is the first step in the process of model improvement.

[7] The second group of publications attempts to analyze the causes of the differences among AOMIP models and

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analyze model errors based on relatively inexpensive numerical experiments with simplified physics [*Proshutinsky et al.*, 2007], by employing methods of data assimilation [*Panteleev et al.*, 2007], by showing how to avoid potential model problems via correct formulation of ice-ocean coupling [*Huang and Jin*, 2007], or by comparing model results with observations to characterize different processes such as Greenland Sea deep convection [*Häkkinen et al.*, 2007], or changes in the intensity and sense of rotation of the Atlantic water circulation [*Karcher et al.*, 2007].

[8] The third group of publications is based on the single model results. The major goal of these studies was to investigate how to parameterize better different arctic processes in order to simulate correctly water and sea ice characteristics in space and time. Among these papers are investigations of the tidal role in the shaping of sea ice and ocean climate [*Holloway and Proshutinsky*, 2007]; investigation on how the internal model parameters or processes influence the Atlantic water circulation [*Golubeva and Platov*, 2007; *Zhang and Steele*, 2007]. *Hunke and Holland* [2007] discuss AOMIP coordinated forcing protocol, raise questions about errors associated with these forcing fields and recommend solutions for detected problems based on the Los Alamos global coupled ice-ocean model.

[9] Alternatively, these papers can be regrouped based on their contributions to the project objectives associated with the second project goal. In this sense, *Karcher et al.* [2007], *Golubeva and Platov* [2007], and *Zhang and Steele* [2007] investigate circulation of Atlantic water layer, its variability in time and causes of the changes. *Holloway and Proshutinsky* [2007] investigate the role of tides and demonstrate how tides modify Arctic Ocean heat content and sea ice volume. *Häkkinen et al.* [2007] investigate variability of the Greenland Sea convection and analyses mechanisms responsible for its variability. *Johnson et al.* [2007], *Gerdes and Köberle* [2007], *Martin and Gerdes* [2007], and *Huang and Jin* [2007] papers describe sea ice thickness, concentration and drift and their spatial and temporal variability. *Panteleev et al.* [2007] analyze the circulation of the Kara Sea and peculiarities of its structure and origin in summer.

3. Major Project Accomplishments

[10] Summarizing the AOMIP scientific findings reported in this section, we would like to list briefly the major project accomplishments. One of the most important accomplishments of this project was obtained in 2000 when AOMIP collaborators met together to share their concerns about arctic model problems. After this meeting, the first model data characterizing the Arctic Ocean seasonal cycle from different AOMIP modeling groups were exchanged among collaborators (note that model parameters and model forcing were not coordinated for this first model intercomparison activity) and striking differences were identified among the model results [*Proshutinsky et al.*, 2001; *Steele et al.*, 2001]. These first steps demonstrated that coordinated model experiments are needed for robust conclusions about model problems, because even small differences in the external forcing fields can generate considerable differences in model results. These results encourage further research and justify the importance of Model Intercomparison Projects (MIPs) activities. At least for the arctic modeling community this was a revolutionary step toward model improvement.

[11] Model improvement includes several phases: (1) identification of problems; (2) search for solutions/improvements; (3) testing improvements based on one or two models; (4) recommendations to others; and (5) introduction and testing of new ideas. Following this scheme, several mechanisms and parameterizations have been applied and analyzed to improve models and model outputs. Of course, the decision to adopt new model physics and/or numerics is left to each modeling team.

[12] An example of AOMIP attempts to improve model physics is the introduction of the "Neptune" effect [*Holloway*, 2004; *Holloway et al.*, 2007]. In addition to Holloway's model (Institute of Ocean Sciences, Canada) this effect is incorporated into several relatively coarse resolution models (Institute of Computational Mathematics and Mathematical Geophysics, Russia [*Golubeva and Platov*, 2007]; Proudman Oceanographic Laboratory, United Kingdom [*Morales Maqueda and Holloway*, 2006]; Laval University, Canada (F. Dupont, personal communication)). It has been shown that this parameterization of eddy-generated entropy drives a "cyclonic rim current" around the Arctic basins, implying that the cyclonic sense of the Atlantic water flow should be relatively persistent even under changing inflow/outflow and wind conditions. Another improvement is associated with the introduction of the second order momentum advection scheme [e.g., *Prather*, 1986; *Hofmann and Morales Maqueda*, 2006; *Morales Maqueda and Holloway*, 2006; *Holloway et al.*, 2007] in several AOMIP models.

[13] There are several ideas remaining from the introduction stage for model improvement. Among them is a recommendation to replace restoring procedures with flux correction, which allows for greater climate variability. This is especially important during significant climate change, as has been observed in the Arctic during last decades.

[14] There are also several studies testing "tidal and inertial hypotheses" to understand the role of tidal and inertial motion in Arctic sea ice and water dynamics. Although evidence indicates that tides play a role in establishing environmental characteristics in the Arctic Ocean [e.g., *Proshutinsky*, 1993; *Kowalik and Proshutinsky*, 1994], this effect has been largely ignored in Arctic climate modeling studies because tidal effects were thought to be negligible. *Holloway and Proshutinsky* [2007] have assessed Arctic tidal effects on the long term climate of the ocean and ice system and showed that tides could be responsible for the loss of heat from the Atlantic water layer leading to ice reduction which is offset by higher ice growth due to ice cover fracturing. *Hibler et al.* [2007] has developed a more realistic formulation of ice-ocean coupling that includes tides and inertial ice motion and their results show that ice-tide interaction is significant.

[15] Furthermore, there are other model improvements and parameterizations which are presently under development. These experiments include atmospheric loading, fast ice parameterizations, improved representations of the Arctic Ocean cold halocline, representations of the correct sea level variability at seasonal and decadal timescales, and mechanisms of freshwater storage and release from both sea ice and liquid ocean reservoirs.

[16] Along with efforts to improve model physics, the AOMIP group has sought to develop new diagnostics. An example is the introduction of topostrophy (defined as **FxV**· **S**, where **F** is Coriolis vector, **V** is model velocity vector, and **S** is gradient of total depth), as seen in *Holloway et al.* [2007], *Karcher et al.* [2007], and *Zhang and Steele* [2007]. In the Arctic, topostrophy diagnoses model's ability to reproduce circulation of Atlantic waters or "cyclonic rim currents". Already this diagnostic is finding wider use in the global modeling community [see *Merryfield and Scott*, 2007].

4. Future AOMIP Plans and Developments

[17] The primary objective of future AOMIP activity is to reduce uncertainty in model predictions by maintaining the basic AOMIP international collaboration via scientific meetings and symposia, liaison activities with other MIPs, disseminating findings of AOMIP effort to broader communities, and training a new generation of ocean and sea-ice modelers. In particular, AOMIP studies will be focused on investigations of: how to better model the arctic halocline which creates the stratification necessary to insulate perennial sea ice from the Atlantic Water layer; and how to avoid restoring and flux correction procedures. These will also answer scientific questions such as: what is the role of different mechanisms influencing heat fluxes in the ocean - sea-ice - atmosphere system? AOMIP will continue investigation of the role of tides in Arctic climate, parameterization of stress-driven and convection-driven mixing and the role of small- meso- and large-scale turbulence (eddies and gyres). Also, AOMIP plans to contribute to the development and implementation of the regional carbon cycle and marine ecosystem models. AOMIP global models will be used to conduct numerical experiments to reveal interactions of the Arctic Ocean with global oceanic and atmospheric changes.

[18] Finally, we would like to thank all AOMIP participants for their enthusiasm, creativeness, and support at all stages of AOMIP establishment, development, and modifications. It is hoped that AOMIP experience and results will be taken into account in the development of new generations of Arctic and global models.

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